July 8, 1969 W. B. BURKETT ET AL 3,454,860

VOLTAGE CUT OFF CIRCUITS

Filed Feb. 25, 1966

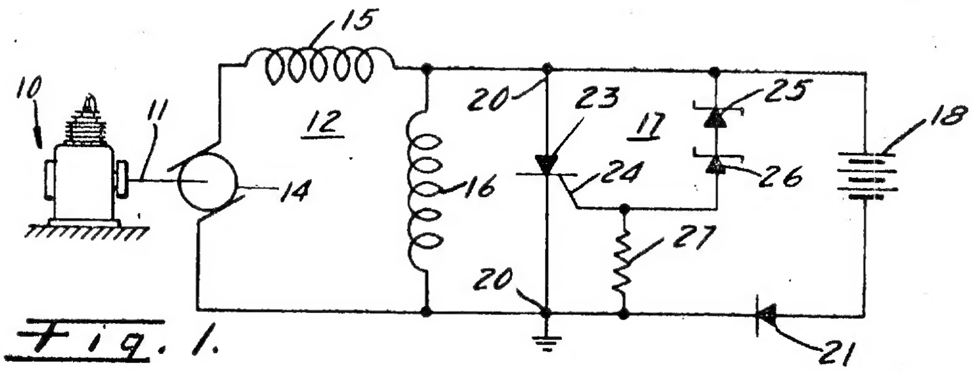

Fig. 1.

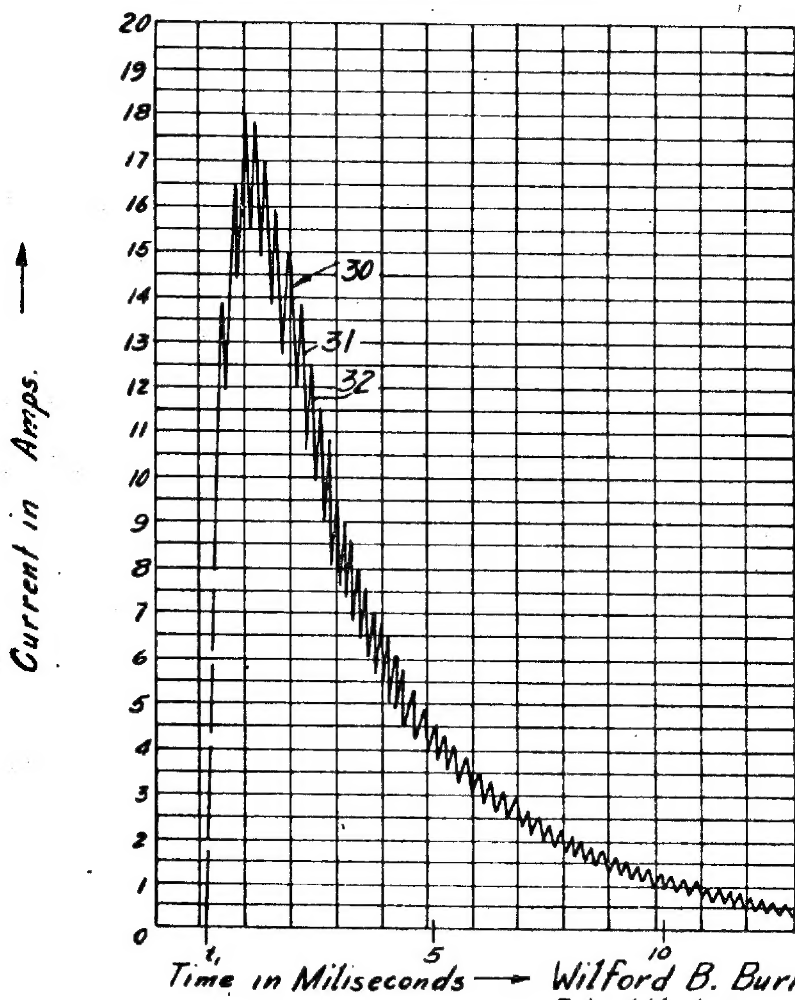

Fig. 2.

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by

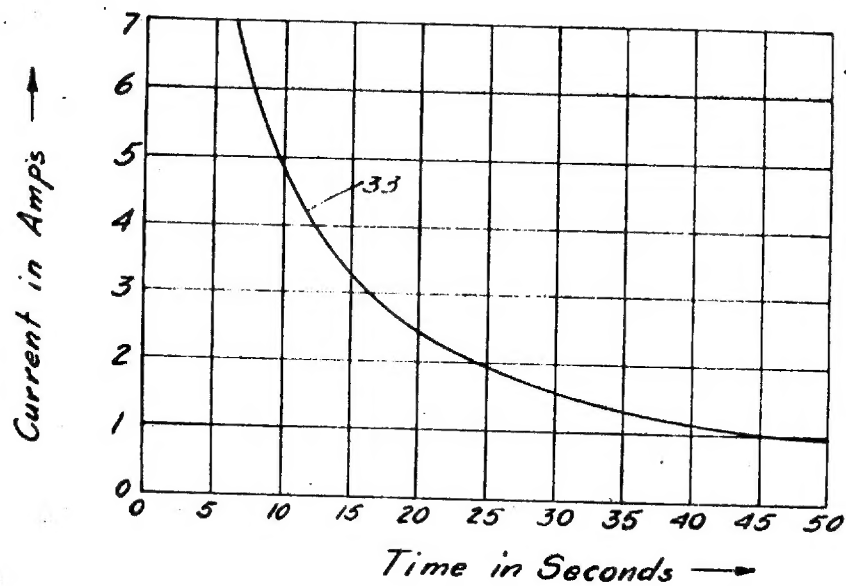

Fig. 3.

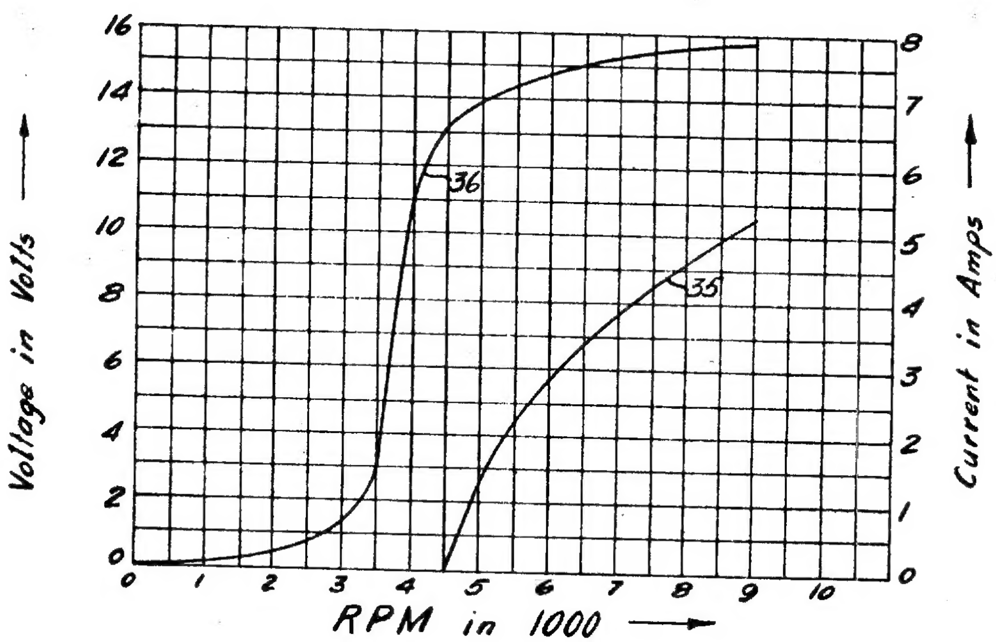

Fig. 4.

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Fig. 10.

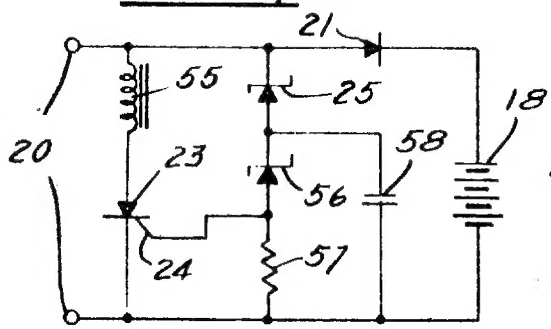

Fig. 13.

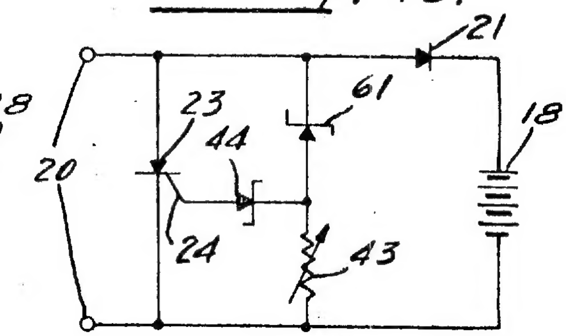

Fig. 11.

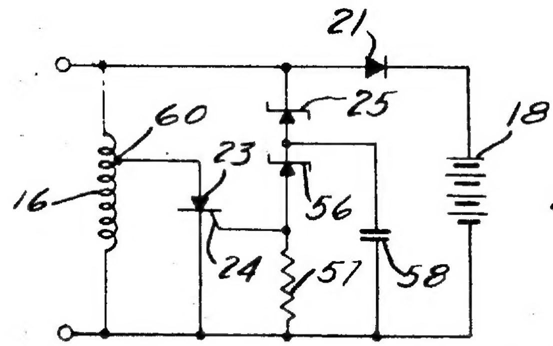

Fig. 14.

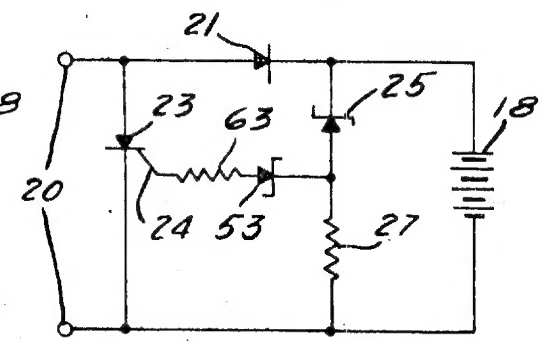

Fig. 12.

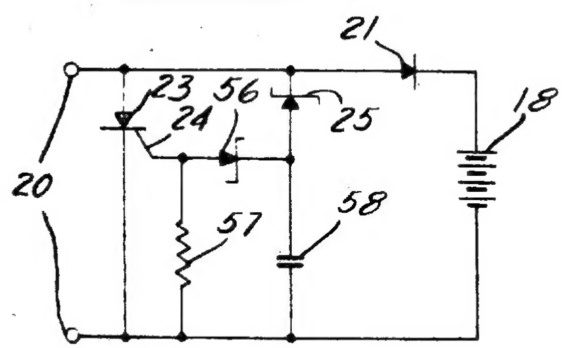

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Fig. 5.

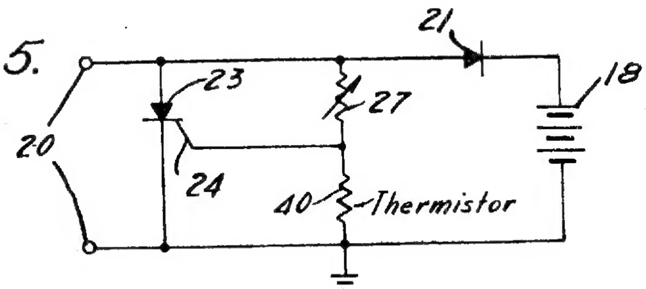


Fig. 6.

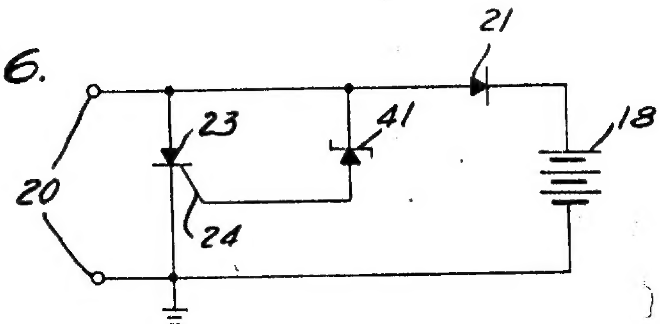


Fig. 7.

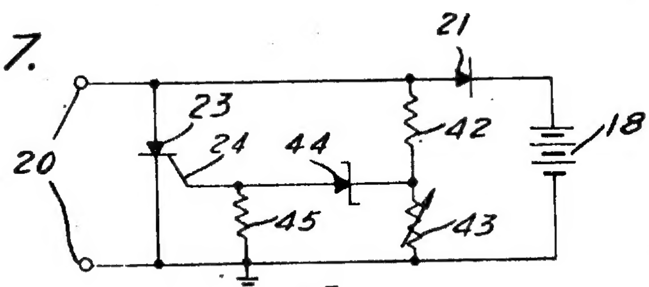


Fig. 8.

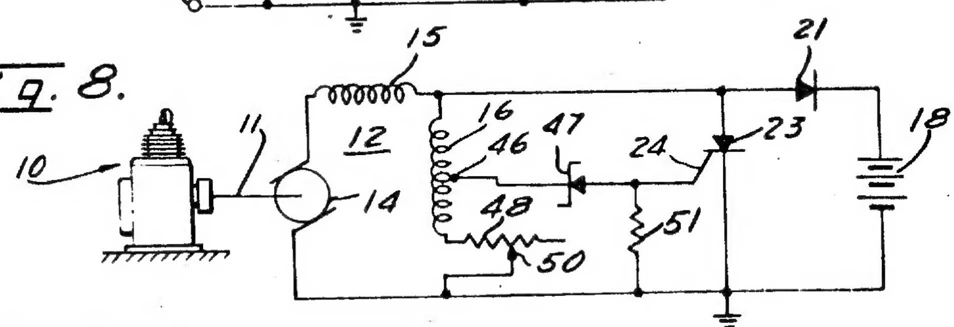
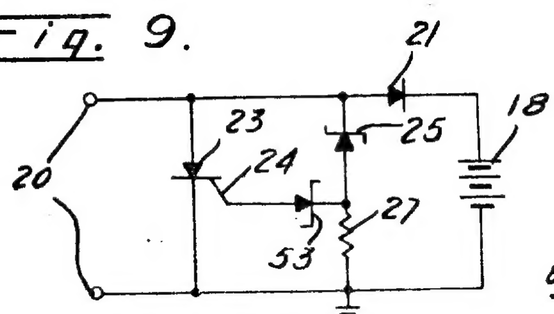


Fig. 9.



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United States Patent Office

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VOLTAGE CUT-OFF CIRCUITS

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Int. Cl. H02j 7/04, 7/16
U.S. Cl. 320—28 12 Claims

ABSTRACT OF THE DISCLOSURE

Voltage cut-off circuits for cutting off the charging current to a battery from a variable direct-current generator having a shunt winding, the circuits include a voltage-responsive switch connected across the shunt winding of the generator for short-circuiting the shunt winding when the battery voltage reaches a predetermined level and a voltage level sensing circuit for controlling the operation of the switch.

This invention relates generally to voltage-responsive circuits, and particularly relates to an electronic circuit for cutting off the charging current between a variable, direct-current voltage source and a battery.

The voltage-responsive circuit of the present invention is particularly designed to cut off the charging current which charges a battery of secondary cells from a DC (direct-current) generator driven by an internal combustion engine with a widely varying speed. For example, the circuit of the present invention is particularly designed for use in connection with a chain saw driven by a single cylinder, two-cycle, internal combustion engine. An electric generator having series and shunt field windings may be mechanically coupled to the engine and may be utilized as the starter for the engine. The battery in turn consists of a plurality of secondary cells such as nickel-cadmium cells that are rechargeable. Thus, by driving the DC motor from the battery, the engine can be started. After the engine has been started, the battery must be recharged. To this end the generator may be directly driven by the engine to supply charging current to the battery.

However, the charging voltage must be closely controlled to avoid damage to the secondary batteries. To this end it may be assumed that the voltage across the battery is an indication of the state of charge of the battery.

It is, accordingly, an object of the present invention to provide an electronic circuit for cutting off the charging current between a variable voltage source and a battery consisting of secondary cells in response to a predetermined voltage across the battery, thereby to prevent damage to the battery.

Another object of the present invention is to provide an electronic circuit for short-circuiting the shunt winding of a DC generator utilized for charging a battery consisting of secondary cells in response to the voltage across the battery having reached a predetermined value, thereby to substantially reduce the output voltage of the generator.

A further object of the present invention is to provide an electronic circuit of the type referred to, which is so designed that it is substantially independent of temperature variations and which nevertheless can be manufactured at a competitive price.

In accordance with the present invention there is provided a voltage-responsive circuit for cutting off the charging current between a variable voltage source such as a DC generator and a battery. The generator is subject to being driven at widely varying speeds and includes

a shunt field winding. A rectifier is connected in series with the battery, the rectifier being so poled as to permit charging of the battery when the voltage across the generator exceeds the battery voltage. There is further provided an electronic switch such, for example, as a silicon controlled rectifier which is connected across the shunt winding of the generator.

This switch is adapted to short-circuit the shunt winding when triggered. The triggering is effected by circuit means coupled to the switch and responsive to the voltage across the battery. Thus, the electronic circuit means may consist of a voltage divider which may, for example, include a Zener or breakdown diode. Preferably the electronic components, particularly the silicon controlled rectifier and the Zener diode, are so designed and arranged as to minimize variation in the voltage response due to changes of temperature which may be caused either by ambient temperature changes or by the operation of the generator and the internal combustion engine connected thereto.

The novel features that are considered characteristic of this invention are set forth with particularity in the appended claims. The invention itself, however, both as to its organization and method of operation, as well as additional objects and advantages thereof, will best be understood from the following description when read in connection with the accompanying drawings, in which:

FIG. 1 is a circuit diagram of a preferred electronic circuit embodying the present invention and including a DC generator;

FIG. 2 is a graph plotting the current as a function of time and showing the current through an electronic switch included in the circuit of FIG. 1;

FIG. 3 is a graph showing the current as a function of time to show the allowable charging period of a secondary or rechargeable cell;

FIG. 4 is another graph showing the voltage as well as the current as a function of the number of revolutions of the engine driving the generator and indicating the characteristics of the generator output voltage and charging current; and

FIGS. 5 through 14 are circuit diagrams of other embodiments of the voltage cut-off circuit of the present invention.

Referring now to the drawings, wherein like elements are designated by the same reference characters, and particularly to FIG. 1, there is illustrated an electronic circuit embodying the present invention. The circuit of FIG. 1 shows the presently preferred embodiment of the invention and includes a prime mover generally indicated at **10** such, for example, as an internal combustion engine. As previously pointed out, the electronic circuit of the present invention is particularly designed for use with a chain saw driven by a single cylinder, two-cycle, internal combustion engine. However, in general, it will be understood that the electronic circuit of the invention is particularly applicable for all types of internal combustion engines where the engine speed varies over a wide range. Examples of such engines are outboard boat engines, engines for automotive vehicles as well as other engines used for portable or transportable power tools and even for stationary applications.

The gasoline engine **10** is preferably directly connected such as by a drive shaft **11** to a DC generator generally indicated at **12**. The DC generator has an armature **14** including the conventional armature windings, a series field winding **15** and a shunt field winding **16**. It should be noted, as shown in FIG. 1, that the series winding **15** and the shunt winding **16** are connected in a closed loop with the armature **14**.

It should be pointed out that the electronic circuit of the invention will operate with any DC generator as

long as it has a shunt winding such as shown at **16**. In other words, the generator may have no series field winding **15** but only a shunt field winding **16**. On the other hand, the generator may have a shunt field winding **16** directly connected across the armature **14** and a series field winding connected in series with the load. In that case the generator may be compounded so that like magnetic poles of the series field winding **15** and the shunt field winding **16** are produced by the field windings. Hence, the two windings **15, 16** are connected in an aiding direction. On the other hand, the two windings may be connected in bucking relationship, that is, unlike magnetic poles may be produced by the field windings. Such a generator is generally referred to as a differentially compounded generator.

The electronic circuit **17** embodying the present invention is connected between the generator **12** and a battery **18** consisting of secondary cells. In other words, it is important that the battery consists of cells which are rechargeable such as nickel-cadmium secondary cells. Hence, the electronic circuit **17** is connected between the output terminals **20** of the generator, one of which may be grounded as shown, and the battery **18**. Connected in series with the output terminals **20** and the battery **18** there is a rectifier or diode **21**. As shown in FIG. 1, the diode **21** has its cathode connected to ground as shown. However, the rectifier **21** may also be connected between battery **18** and series field winding **15**. The rectifier **21** is preferably a semiconductor diode but not necessarily so. It is so poled as to block current flow from the battery **18**. Charging current to the battery occurs when the voltage of the generator **12** developed across the output terminals **20** exceeds a predetermined value. This is determined by the voltage across the battery **18** and the forward voltage drop across the diode **21**.

Connected across the battery **18** and the diode **21** there is a multilayer diode **23** commonly known as a silicon controlled rectifier which may, for example, consist of an NPNP four-layer diode and operates as an electronic switch. This type of rectifier is provided with a gate or control electrode **24**. The silicon controlled rectifier **23** is normally non-conductive. However, it does become conductive when a voltage of a given polarity and magnitude is applied across the device **23** and provided a voltage signal of predetermined magnitude is applied to its control electrode **24**. In order to do this, there is provided a voltage divider circuit across the battery **18** and diode **21**. This consists of two Zener diodes **25** and **26** connected in series and a resistor **27**, their junction point being connected to the control electrode **24**.

A Zener diode is also known as a breakdown diode and has such characteristics that it permits a current flow in a reverse direction through the diode only when the voltage across the diode exceeds a predetermined value. At that voltage the diode breaks down and begins to conduct. Obviously one of the Zener diodes such as diode **26** may be omitted.

The operation of the voltage cut-off circuit of the invention will now be explained. It is assumed the battery **18** is discharged from time to time. For example, its function may be to drive the generator **12** which then operates as an electric motor for starting the gasoline engine **10**. To this end, of course, there must be a switch bypassing the diode **21**. However, as far as the present invention is concerned all that is necessary is that the battery **18** has previously been discharged.

When the gasoline engine **10** driving the generator **12** reaches a certain speed, an output voltage is developed across the generator output terminals **20**. Accordingly, when the output voltage developed at the generator output terminals **20** exceeds the forward voltage drop of diode **21** and the battery voltage, a charging current flows through the battery **18**. As a general rule and as an approx charge for any secondary cell battery. As a result the battery voltage increases as the percentage of the charge increases. Thus, the forward voltage drop of the diode **21** may, for example, be 0.6 volt. It may further be assumed that the battery **18** consists of 10 secondary cells each rated at 1.25 volts so that the nominal voltage across the battery **18** is 12.5 volts and may be as high as 15 volts.

Accordingly, assuming the flow of a charging current, the battery voltage increases and the generator output voltage also rises. This generator output voltage appears across the two Zener diodes **25, 26** and the resistor **27**. The two Zener diodes **25, 26** are so selected that they conduct current in response to a predetermined voltage thereacross. Thus, when the voltage across the generator output terminals **20** reaches a certain value, the two Zener diodes **25, 26** will conduct and there will be a voltage drop across the resistor **27**. This voltage drop appears at the control electrode **24**. Assuming that this voltage is sufficiently high, it will trigger the silicon controlled rectifier **23** which subsequently becomes conductive.

This now short-circuits the shunt winding **16** and bypasses the field current of the generator. As a result, the generator loses excitation and the output voltage of the generator decreases to a small value. This small output voltage is sustained by the residual induction or remanence of the magnetic circuit of the generator.

Referring now to FIG. 2 there is illustrated a curve showing the current in amperes flowing through silicon-controlled rectifier **23** as a function of time in milliseconds. This curve shows that the current through the silicon-controlled rectifier **23** quickly reaches a peak value, then decays in a generally exponential fashion when the silicon-controlled rectifier becomes conductive.

It will be noted that the curve **30** consists of a multitude of individual falling curve portions such as **31** and rising curve portions such as **32**. These are caused by the shape of the commutator of the generator and the speed of the generator. However, in any case, it is apparent that the charging current very rapidly decays within a matter of a few milliseconds.

Referring now to FIG. 3 there is illustrated a curve **33** showing the maximum permissible charging current in amperes as a function of time in seconds. Thus, any charging current for a nickel-cadmium cell below curve **33** is safe while any current above or to the right of curve **33** is unsafe. This curve clearly shows that such nickel-cadmium secondary cells will stand a very high charging current for a short period but can only accept a relatively low charging current for any extended period of time. In accordance with the present invention use is made of this curve because the battery is charged very rapidly with a large current but for a short period of time. As a result, the battery is again ready to be used, for example, for driving the generator **12** as a motor to start the gasoline engine **10**.

FIG. 4 depicts both the generator output voltage across terminals **20** and the battery charging current as a function of the number of revolutions (r.p.m.) of the gasoline engine **10**. Thus, the r.p.m. are shown in units of thousands in FIG. 4. The battery charging current is shown by curve **35** while curve **36** indicates the generator output voltage. It will be noted that the output voltage rises rapidly as the engine speed exceeds approximately 3,500 r.p.m. Below that value there is no charging current because the generator output voltage must exceed a certain value as pointed out before, such as about 13 volts before the charging current can flow through the diode **21**.

It will thus be apparent that the cut-off circuit of the present invention operates in essence as a voltage limiter. It is triggered when the battery voltage exceeds a certain value and, hence, is sensitive to voltage. But it will not permit the generator output voltage to rise above a certain

As long as the generator is driven above a certain speed, say about 4000 to 5000 r.p.m., the residual magnetism in the yoke and in the field poles of the generator will be sufficient to maintain the silicon controlled rectifier **23** conductive. However, assuming that the prime mover **10** decreases its speed below some critical value; in that case there will not be enough voltage across the silicon controlled rectifier **23** for it to remain conductive. Accordingly, the controlled rectifier **23** now becomes nonconductive.

As the speed of the prime mover **10** increases again, the generator output voltage rises as shown by curve **36**. Then, assuming that the battery had previously been charged sufficiently, the same sequence of events takes place again. In other words, the silicon controlled rectifier **23** is again made conductive, thereby to short-circuit the shunt winding **16** and to reduce the generator output voltage sufficiently to prevent further charging of the battery **18**. Thus, the action of the voltage cut-off circuit of the invention is to limit battery voltage to a predetermined level that keeps the battery close to full-charged condition and protects the battery from charging to too high a voltage that can damage the battery.

The voltage cut-off circuit of FIG. 1 is further designed to be substantially insensitive to wide variations of ambient temperature. For example, a chain saw may have to be used at both below freezing temperatures and in hot climates. In addition, of course, the generator **12** and the gasoline engine **10** may cause the circuit to heat up. On the other hand, Zener diodes such as **25**, **26**, silicon controlled rectifiers and diodes are all temperature sensitive. Therefore, preferably all of the solid state components such as **21**, **23**, **25** and **26** are disposed close to each other or are arranged in a common housing. This will insure that there is little temperature differental between these components. For example, the diodes **21** and the silicon controlled rectifier **23** operate at a decreasing voltage when the temperature increases. On the other hand, the Zener diodes can be selected to break down at an increasing voltage withi ncreasing temperature or to break down at a decreasing voltage with increasing temperature. Thus, advantage can be taken of this situation to provide for an inherent temperature compensation, or a positive or negative temperature coefficient.

It should also be pointed out that the generator **12** is preferably so designed that it has inherently poor regulation. As a result, the current surge of the generator is low. This, in turn, makes it possible to utilize less costly components. For example, the silicon controlled rectifier **23** may be designed for a normal current of 1.6 amperes. Nevertheless it can handle a surge current for a short period up to 20 amperes.

The circuit of FIG. 1 shows two Zener diodes **25** and **26** in series. This permits a better temperature compensation. It is economically less expensive to provide a pair of Zener diodes which will break down at a predetermined voltage within 1%. This can be arranged by two complementary Zener diodes. This is less expensive than to provide a single Zener diode designed to break down at a certain voltage with a 1% variation.

Of course, on the other hand, one of the two Zener diodes, such as **26**, may be omitted or more than two Zener diodes may be used. The circuit of FIG. 1 with only one Zener diode is characterized by its simplicity and by the few components required. If the Zener diode or diodes are correctly chosen for the proper breakdown voltage, no adjustment is needed, for example, of the resistor **27**.

On the other hand, the disadvantage of a circuit with a single Zener diode is that it becomes more difficult to fully compensate for temperature variations. Also, as pointed out before, this requires a single Zener diode which must conduct at a set voltage within 1% and such units are more expensive.

While it will be understood that the circuit specifications of the voltage cut-off circuit of the invention illustrated in FIG. 1 may vary according to the design for any particular application, the following specifications are included, by way of example, only:

Battery **18**	13.3 volts.
Silicon controlled rectifier **23**	Motorola type MCR 2304 or MCR 808.
Zener diodes **25** or **26**	IN958.
Rectifier **21**	Motorola type MR 322 (silicon rectifier) rated at 18 amps. at 15 volts DC.
Resistor **27**	1200 ohms.

The circuit of FIG. 1 is arranged to cut off when the battery voltage has reached 15 volts. The two Zener diodes **25** and **26** are selected for a nominal Zener or breakdown voltage of 7.5 volts.

Further modifications of the voltage cut-off circuit of the present invention are illustrated in FIGS. 5 through 14. Thus, referring to FIG. 5 there is shown a voltage cut-off circuit which does not require any Zener diode. Instead a thermistor **40** is connected in series with the resistor **27**, their junction point being connected to the control electrode **24** of the silicon controlled rectifier **23**. This circuit otherwise operates in the same manner as does that of FIG. 1. Further description of the operation therefore is not needed. It should be noted that the diode **21** is now provided between the battery **18** and the series winding **15**. The generator **12** has not been shown but only the generator output terminals **20**.

The advantage of the circuit of FIG. 5 is that it has a temperature compensating resistor, namely, the thermistor **40**. This thermistor **40** can be chosen to match the temperature characteristic of the silicon controlled rectifier **23**. The resistor **27** may be adjusted at room temperature for the proper trigger voltage.

On the other hand, the circuit of FIG. 5 has the disadvantage that it is difficult to obtain complete temperature compensation over a sufficiently wide temperature range by means of a thermistor to match all silicon controlled rectifiers. Hence, only a partial compensation is possible in practice. It will be realized that in a production run various silicon controlled rectifiers have varying properties and, hence, it is difficult to match the temperature characteristics of a production run of silicon controlled rectifiers with another production run of thermistors.

Thus, in the circuit of FIG. 5 the operating voltage must be present at a particular temperature and this may not be correct at other temperatures.

FIG. 6 illustrates another modification of the invention. In this circuit the resistor **27** has been omitted. Instead there is only a single Zener diode **41** connected between the diode **21** and the control electrode **24** of the silicon controlled rectifier **23**. However, there is still a voltage divider consisting of the Zener diode **41** and that portion of rectifier **23** from control electrode **24** to ground.

This circuit can be compensated for changes of the ambient temperature. This ambient temperature may vary between a minimum of −20° F. (Fahrenheit) to a maximum of 150° F. The circuit is quite similar to that of FIG. 1, but it is even simpler because it requires no resistors.

The disadvantage is that the temperature characteristic of the control electrode of the silicon controlled rectifier **23** in turn varies with the temperature. Thus, this requires a precise selection of the Zener diode **41**.

The circuit of FIG. 7 includes a voltage divider consisting of a fixed resistor **42** and a variable resistor **43** connected across battery **18** and diode **21**. The junction point between resistors **42** and **43** is connected with the control electrode **24** of the silicon controlled rectifier **23** through a Zener diode **44**. Furthermore, a resistor **45** connects the control electrode **24** to ground.

In the circuit of FIG. 7 it will be understood that the resistor **45** may be omitted. Discussing first the circuit